Potential Effects of Structural Controls and Street Sweeping on Stormwater Loads to the Lower Charles River, Massachusetts

In cooperation with the:
U.S. Environmental Protection Agency
Massachusetts Department of Environmental Protection, and the
Massachusetts Water Resources Authority

Photo courtesy of: Philip Greenspun   http://philip.greenspun.com

USGS
science for a changing world

Study area


EASTERN MASSACHUSETTS
LOGAN AIRPORT
ATLANTIC OCEAN
UPPER CHARLES RIVER WATERSHED
LOWER CHARLES RIVER WATERSHED
CAMBRIDGE
71°8
71°4
71°12'
NEW CHARLES RIVER DAM
WATERTOWN DAM
USGS-CR3
42°22
WATERTOWN
UNGAGED MODEL AREA
MUSEUM OF SCIENCE
BWSC-CS4
FANEUIL BROOK SUBBASIN
LAUNDRY BROOK SUBBASIN
Village Brook Subbasin
42°20
MWRA-WS5
BOSTON
Single-family land-use subbasin
MUDDY RIVER SUBBASIN
BROOKLINE
NEWTON
42°18
STONY BROOK SUBBASIN
BWSC-WS6
EXPLANATION
Precipitation gage
Surface water
Municipal boundary
Subbasin boundary
42°16
0 1 2 Miles
0 1 2 3 Kilometers

Objective

Assess the potential non-CSO stormwater load reductions that can be achieved by implementing Best Management Practices (BMPs):

- Structural controls
- Street sweeping

Structural Controls

- Retrofit study by Center for Watershed Protection (CWP)
- Identified structural controls in a cross-section of subbasin types – focused Village Brook Subbasin
- CWP study did not evaluate potential load reductions

Structural Control Village Brook Subbasin

CWP No.	Category	Contributing drainage area (mi^2)	Runoff treated (inches)	Site Location	CWP No.	Category	Contributing drainage area (mi^2)	Runoff treated (inches)	Site Location
VB-1	Biofiltration - Bioretention	0.0023	1.0	Boston College Alumni Field Parking	VB-11	Infiltration-Filtration	0.0016	1.0	Lincoln Primary School
VB-2	Biofiltration - Bioretention	0.0438	1.0	Cleveland Circle	VB-12	Infiltration-Filtration	0.0781	0.5	Cypress Playground
VB-3	Infiltration-Filtration	0.0047	0.5	Chestnut Hill nr. Cleveland Circle	VB-13	Infiltration-Filtration	0.1563	0.33	Robinson Playground
VB-4	Infiltration-Filtration	0.0938	0.5	Waldstein Playground	VB-14	Biofiltration - Bioretention	0.0005	1.0	Brookline Public Housing nr. Chestnut St. and Pond. Ave.
VB-5	Detention-Retention	0.1016	0.5	Reservoir Rd. and Crafts Rd.	VB-15	Infiltration-Filtration	0.2266	0.25	Adjacent to Willow Pond
VB-6	Infiltration-Filtration, Biofiltration - Bioretention	0.0047	0.5	Boylston St. nr. Reservoir Rd.	VB-16	Detention-Retention	--	--	Willow Pond
VB-7	Biofiltration - Bioretention	0.0031	1.0	Fairway Rd. nr. Reservoir Rd.	VB-17	Detention-Retention	--	--	Leverett Pond
VB-8	Biofiltration - Bioretention	0.0063	1.0	Runkle Elementary School	VB-18	Biofiltration - Bioretention	0.0047	1.0	Park nr. North End of Leverett Pond
VB-9	Biofiltration - Bioretention	0.0047	0.5	Newbury College	VB-19	Detention-Retention	--	--	Village Brook Outfall to Leverett Pond
VB-10	Biofiltration - Bioretention	0.0023	0.75	Newbury College					

Collectively 21% contributing DA

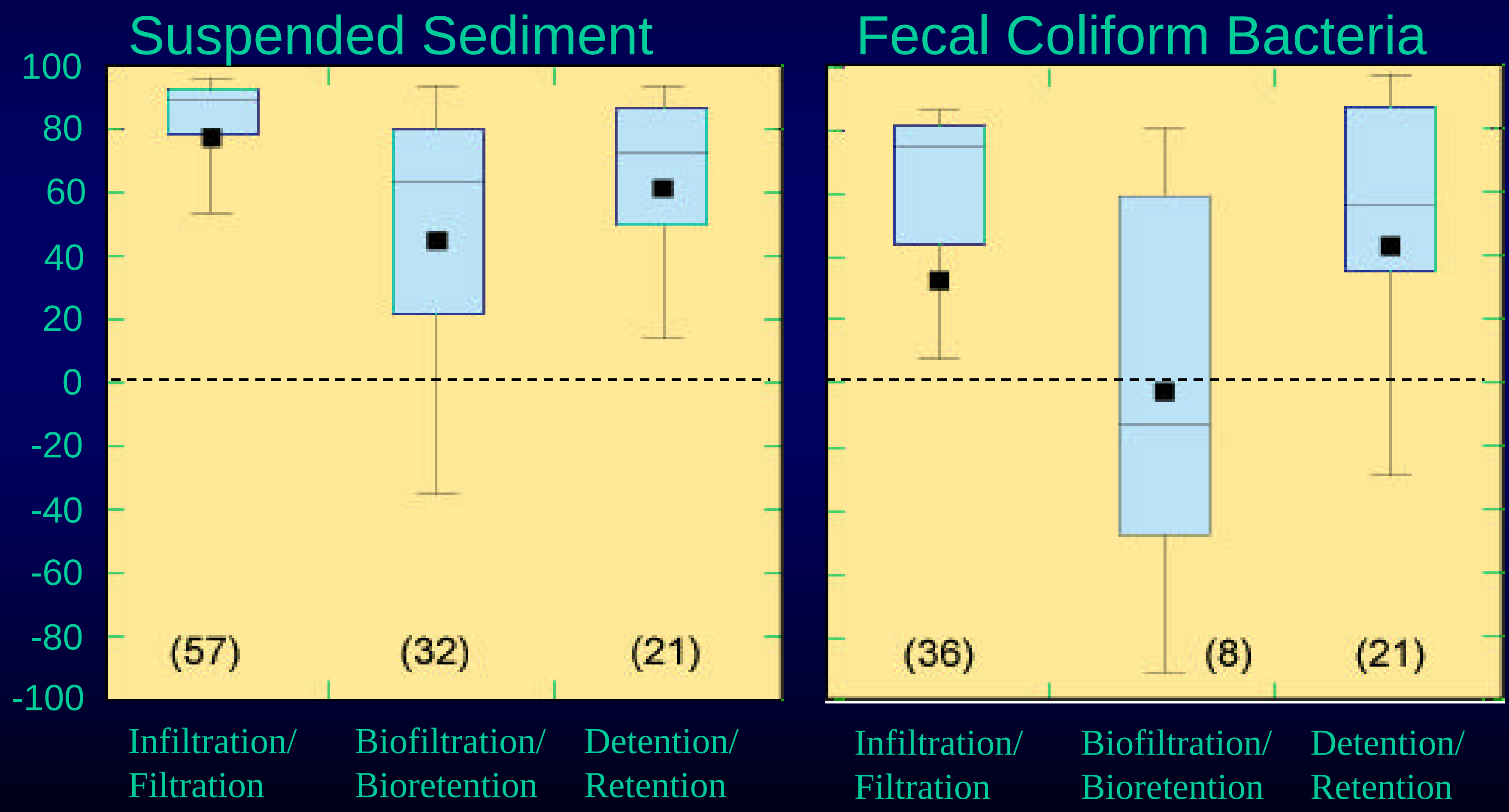
Structural Control Types

Category	Types of controls	Major physical or chemical process	Characteristics
Infiltration-Filtration	Infiltration trenches, infiltration basins, underground filters, surface filters, organic media filters, porous pavement	Infiltration, adsorption, straining, chemical transformation, microbial decomposition	Adequate soil media critical; effective suspended solids removal; regular maintenance essential to prevent clogging
Biofiltration-	Bioretention, dry and wet swales, vegetated filter strips	Biodegradation, precipitation, infiltration, filtration, adsorption	Adequate soil media critical; low cost; easy to install
Bioretention	Detention ponds, wetlands/shallow marsh systems, detention tanks and vaults, oil-grit separators, catch basin inserts, manufactured systems	Particulate settling and biological filtering (wetlands)	Adequate hydrology and soils required for retention/wetlands; mainly pretreatment

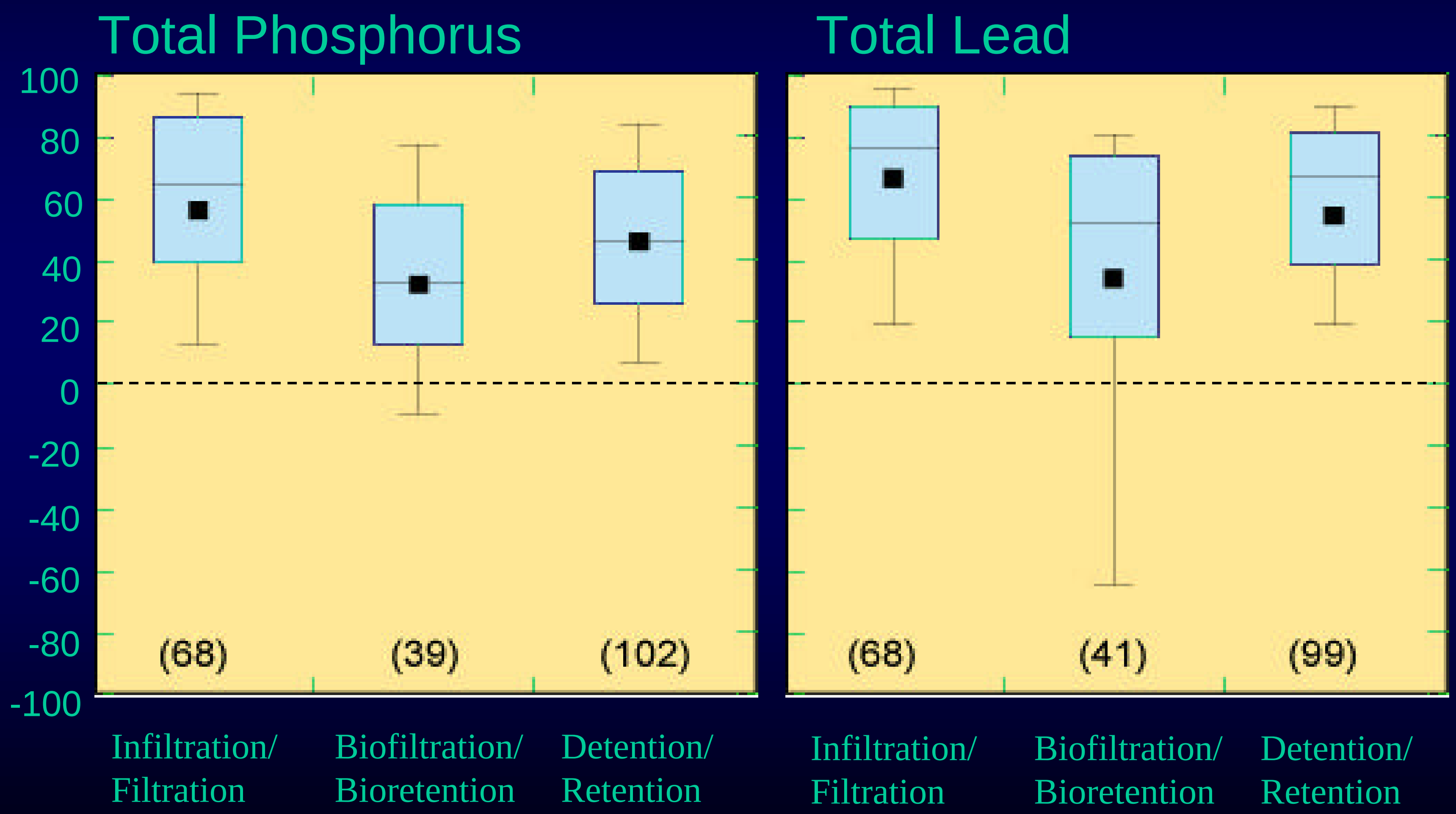
Structural Control Removal Efficiencies

- National Pollution Removal Performance Database for Stormwater Best Management Practices (Brown and Schueler, 1997)
- Stormwater Best Management Practices in Ultra-Urban Settings: Selection and Monitoring (Shoemaker and others, 2000)
- National Stormwater Best Management Practices Database (ASCE, 2002)

Structural Control Removal Efficiency



Structural Control Removal Efficiency



Percent Decrease in Constituent Loads – Village Brook

Removal	Suspended Solids	Fecal Coliform	Total Phosphorus	Total Lead
Stormwater load				
Average	15	6.4	11	13
Lower quartile	15	7.8	7.5	9.3
Median	17	13	12	15
Upper quartile	19	16	17	18
Total load				
Average	15	6.2	9.2	12
Lower quartile	14	7.5	6.2	8.9
Median	17	13	10	15
Upper quartile	18	16	14	17

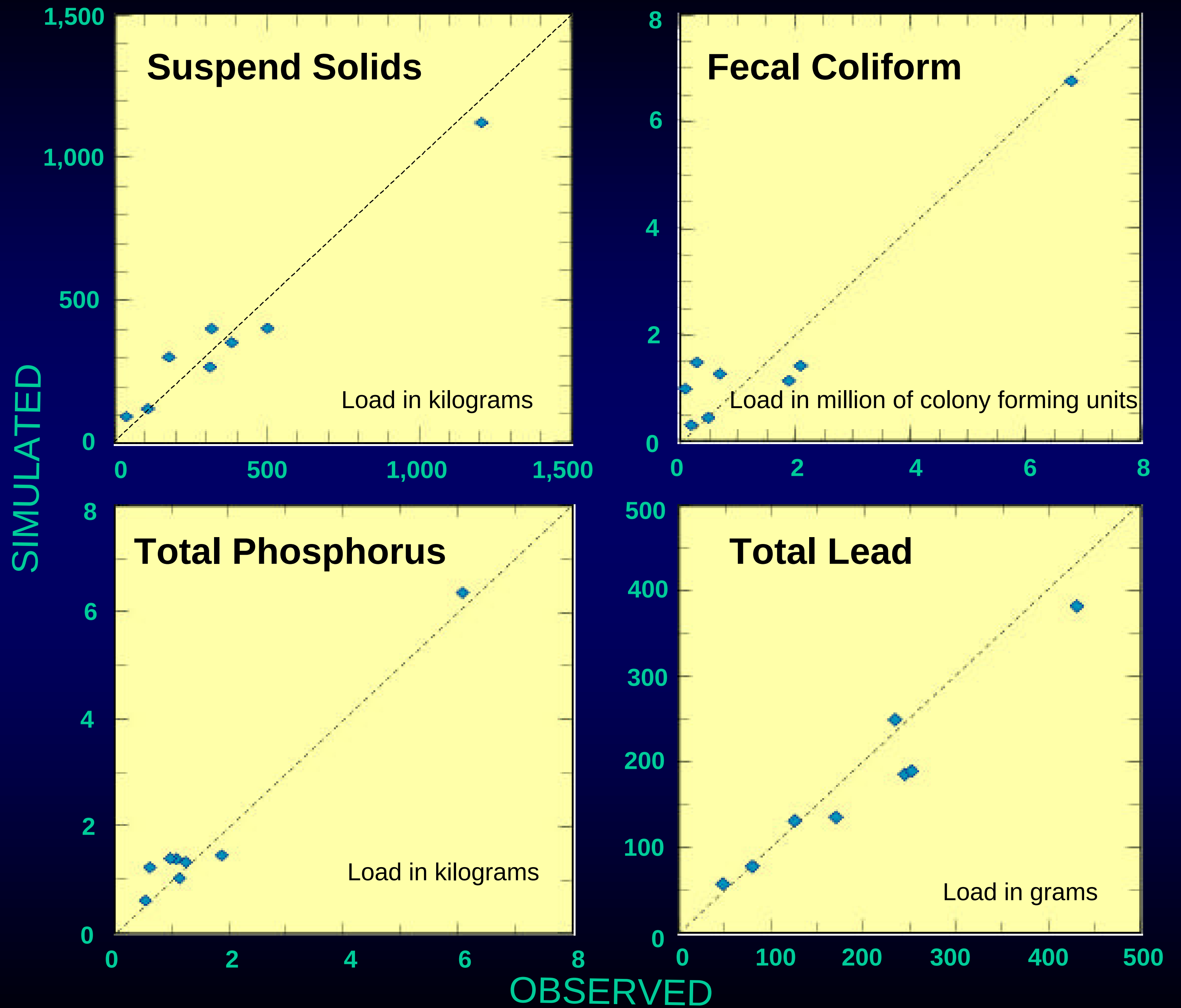
Street Sweeping

- Potentially important BMP because of limited opportunities for structural controls
- Streets are a large source of contaminates, generally 70-80 total load
- Improvements in sweeper technology

Approach

- Add water quality to the SWMM simulation of the single-family residential land-use subbasin,
- Simulate effects of different sweeping efficiencies and frequencies,
- Apply removal efficiencies to other subbasins.

Storm Calibration



Sweeper Types and Efficiencies

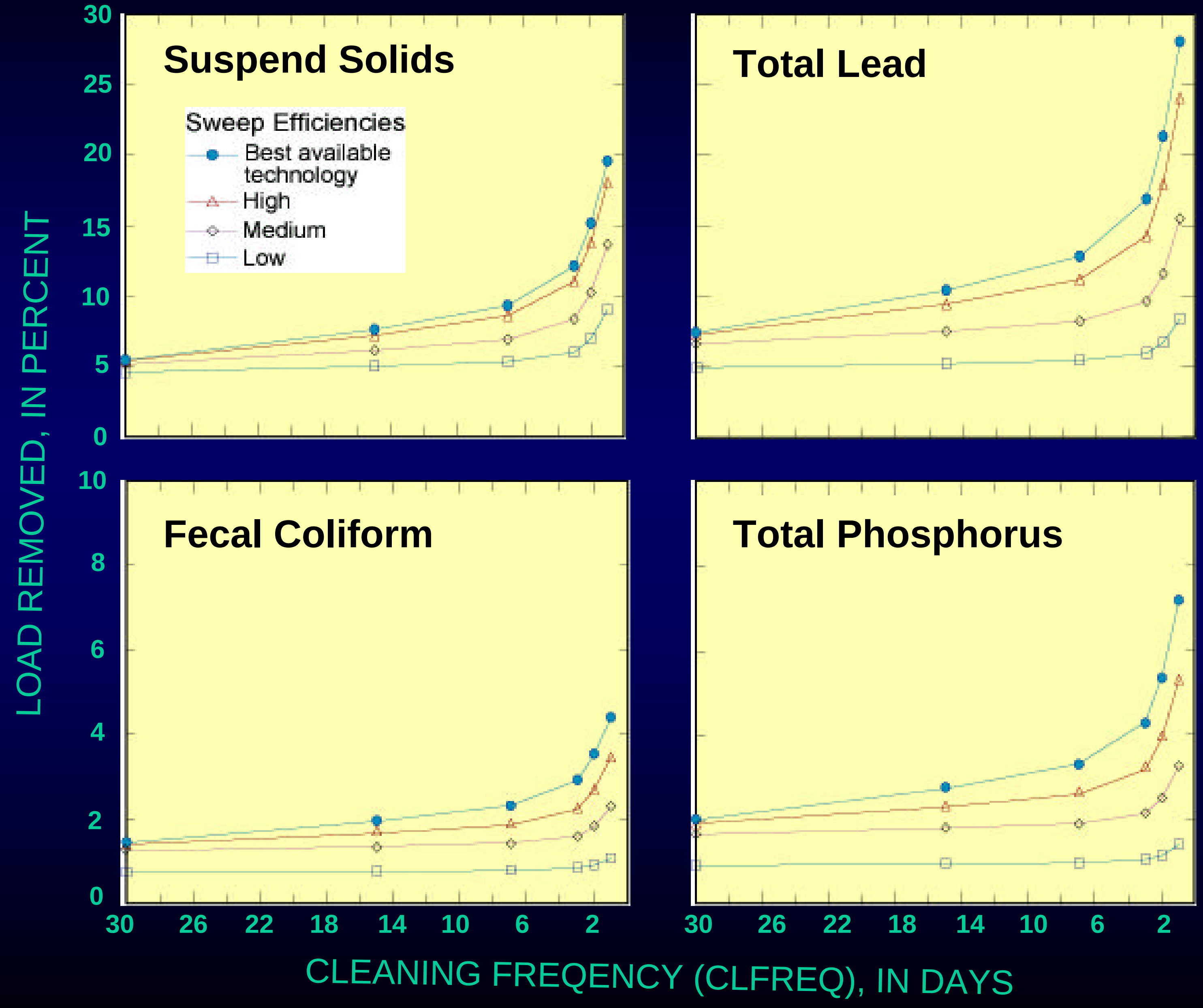
Type	Suspended solids	Fecal coliform	Total phosphorus	Total lead
Mechanical	25	5	5	10
Wet vacuum and regenerative air	45	20	20	30
Dry vacuum	80	50	50	70
Best available technology	95	90	90	95

Availability factor of 0.80 was applied to all sweepers

Sweeper Frequency

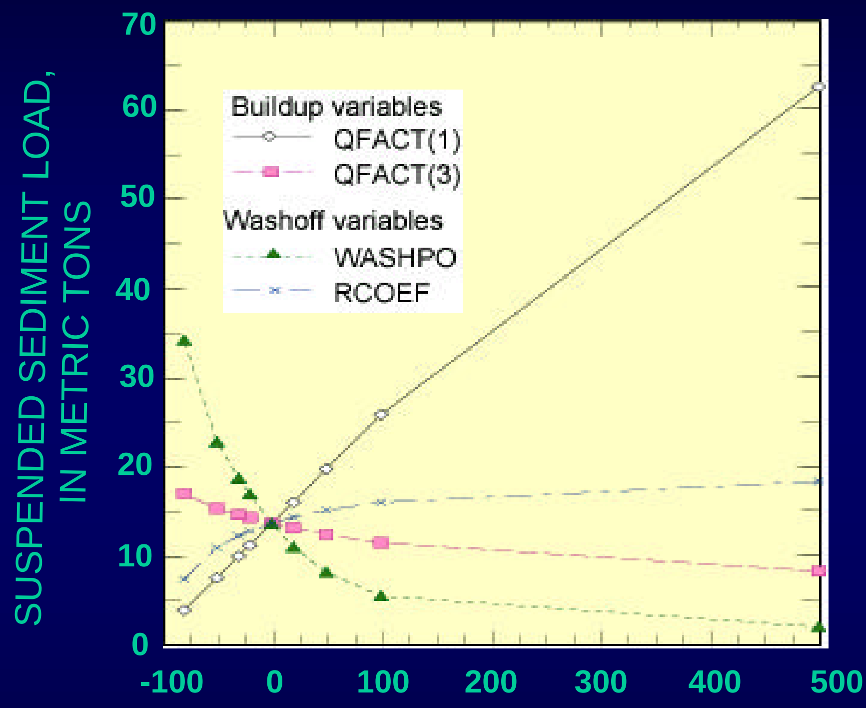
- Inter-event dry period averaged 85 hours (1970-95),
- 6 frequencies (CLFREQ) simulated– monthly, bi-monthly, weekly, bi-weekly, every other day, daily,
- CLFREQ only counts periods of no runoff (<0.0005 inches), therefore the actual frequency could be greater than the frequency specified.

Simulated Load Removed by Sweeping

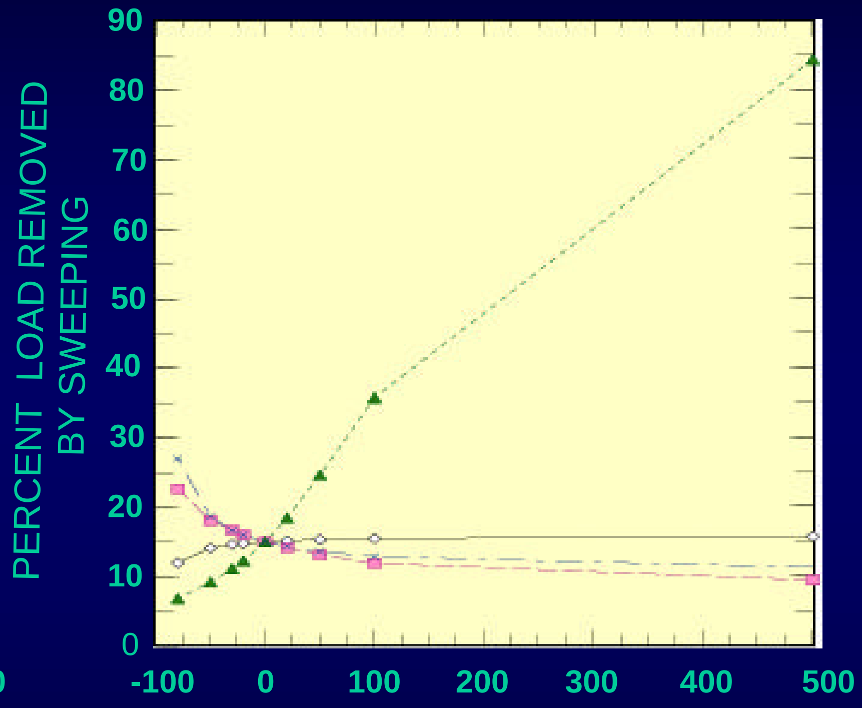


Sensitivity of Model Buildup and Washoff Variables

Runoff Load



Load Removed by Sweeping



PERCENT CHANGE IN VARIABLE

$$Q = \frac{QFACT(1) \times t}{QFACT(3) + t}$$

Q - built-up load,
QFACT(1) - buildup limit,
QFACT(3) - time for the buildup load to reach half the buildup limit

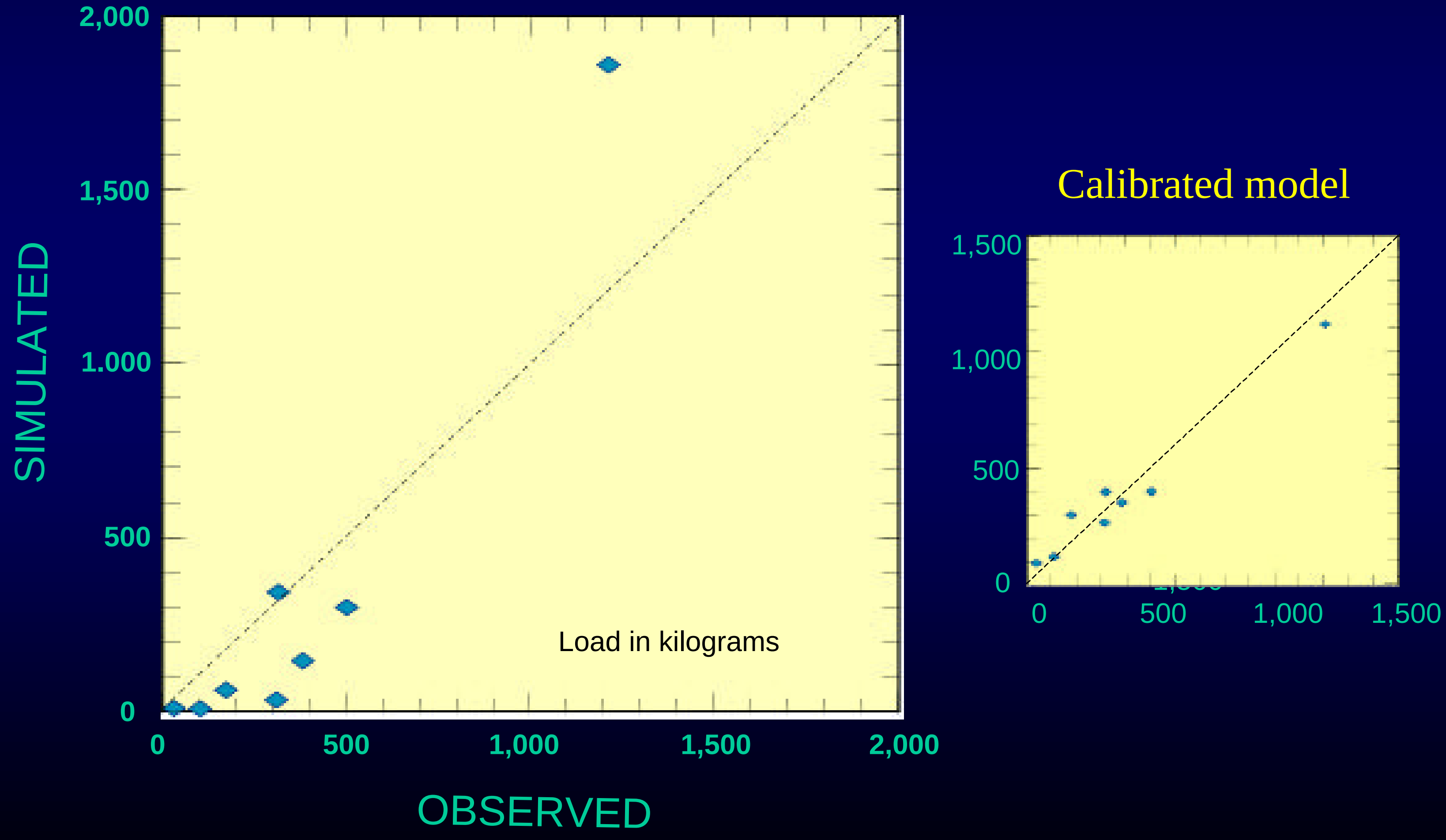
$$POFF = RCOEF \times r^{WASHPO} \times PSHED$$

POFF - load washed off at time each time step (mass/time)
RCOEF - washoff coefficient,
R - runoff rate (in./hr),
WASHPO - exponent of the runoff rate
PSHED – quantity of the constituent load available for washoff at each time step

Alternative model

- Increased WASHPO by 60% (1.85 to 3.0)
  Decreased RCOEF by 80% (10.7 to 2.0),
- Alternative variable values improved storm-fit for 3 July but adversely effected fit for other storms,
- Caused suspended solids load removed by sweeping to increase about 4.5 times (from 15% to 66%) for simulations with a 2-day frequency and 76% effective efficiency,
- Generally improved removal by sweeping by 3 fold for suspended solids, 20% for fecal coliform, 40% for total Phosphorus, and 2 fold for total lead.

Alternative model suspended sediment calibration



Extrapolation of Model Results

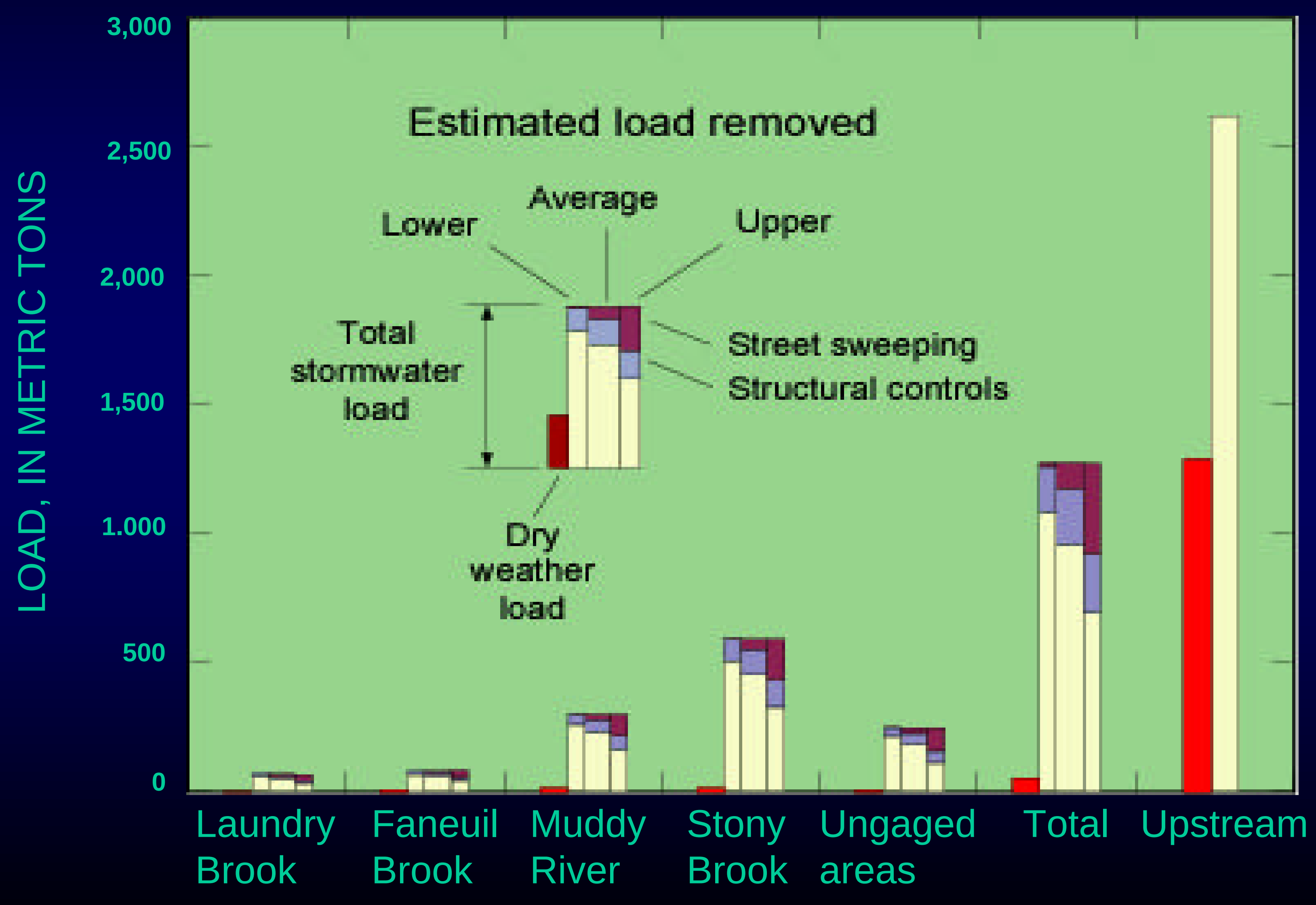
- Road density weighting factor
  Ratio of street density in the single-family land use subbasin to other basins
- Street load to subbasin load method
  Estimates subbasin street load (simulated from the load per mile of street in the single –family subbasin) relative to the subbasin load
  Suspended solids – 3.61 kg/d/mi
  Fecal coliform – 13.95 CFU/d/mi
  Total phosphorus – 14 g/d/mi
  Total lead – 2.05 g/d/mi
- Road density weighting factor generally resulted in more removal than the loads method

Combined Structural Control and Sweeper Percent Load Removed

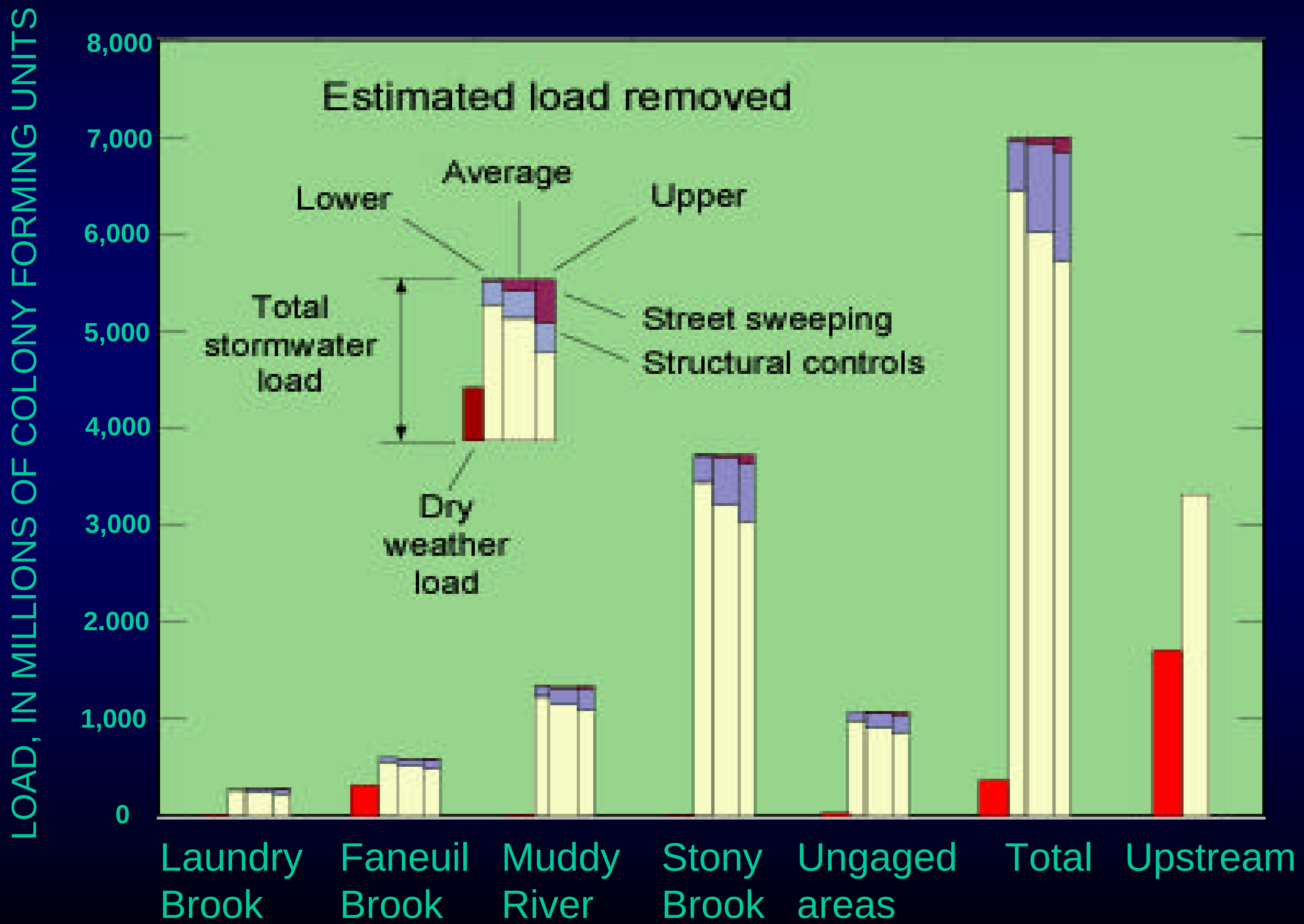
	Lower	Average	Upper
Percentage of non-CSO load below Watertown Dam			
Suspended solids	14	24	44
Fecal coliform	7.5	13	17
Total phosphorus	4.9	8.7	14
Total lead	11	21	34
Percentage of non-CSO load from the entire watershed			
Suspended solids	3.7	6.1	11
Fecal coliform	4.4	7.9	10
Total phosphorus	1.0	1.8	2.8
Total lead	4.1	8.1	13

Lower – Low efficiency sweeper, 30 day, lower quartile
Average – High efficiency sweeper, bi monthly, median quartile
Upper – Best available technology sweeper, weekly, upper quartile

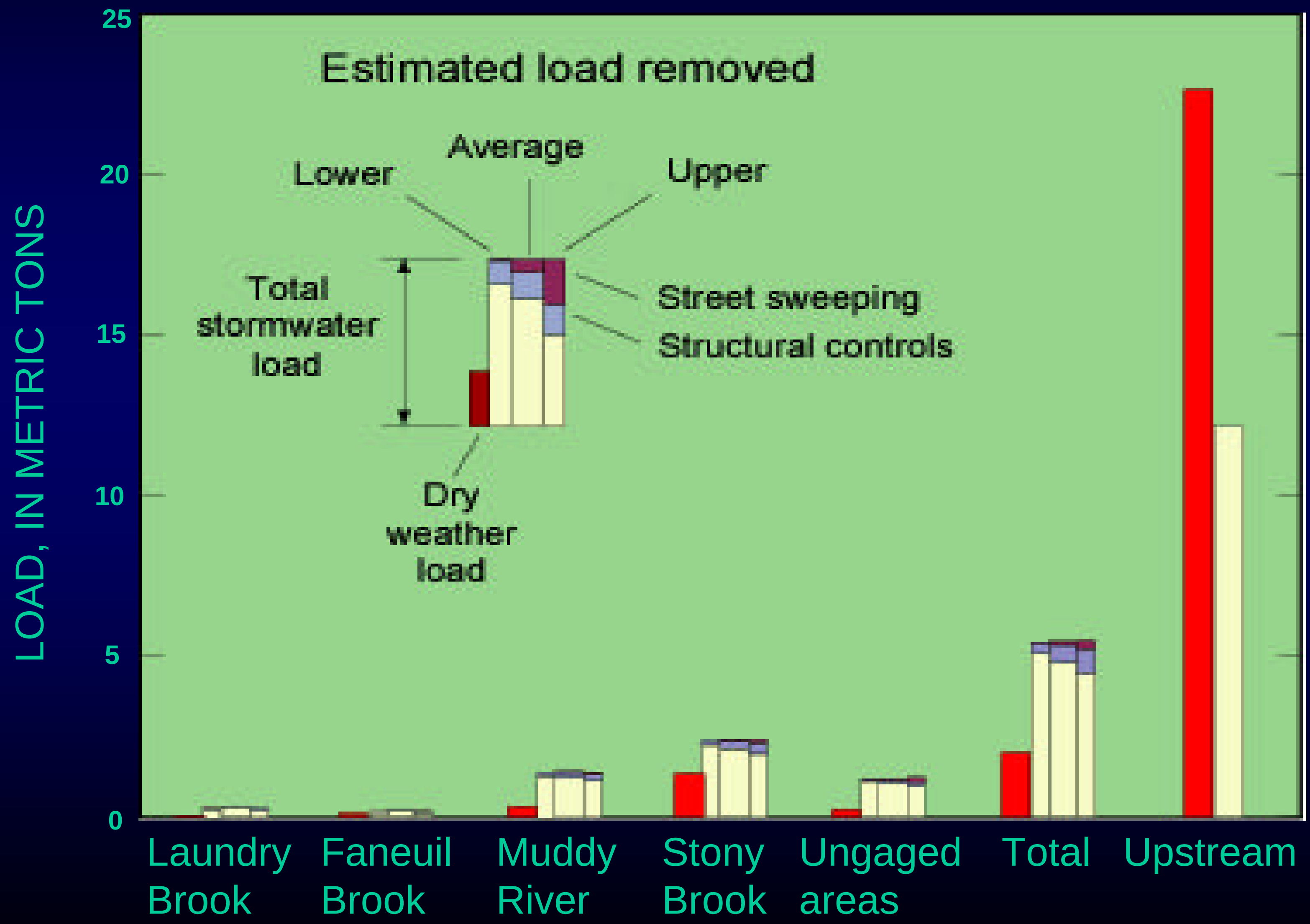
Suspended Sediment – 2000 WY



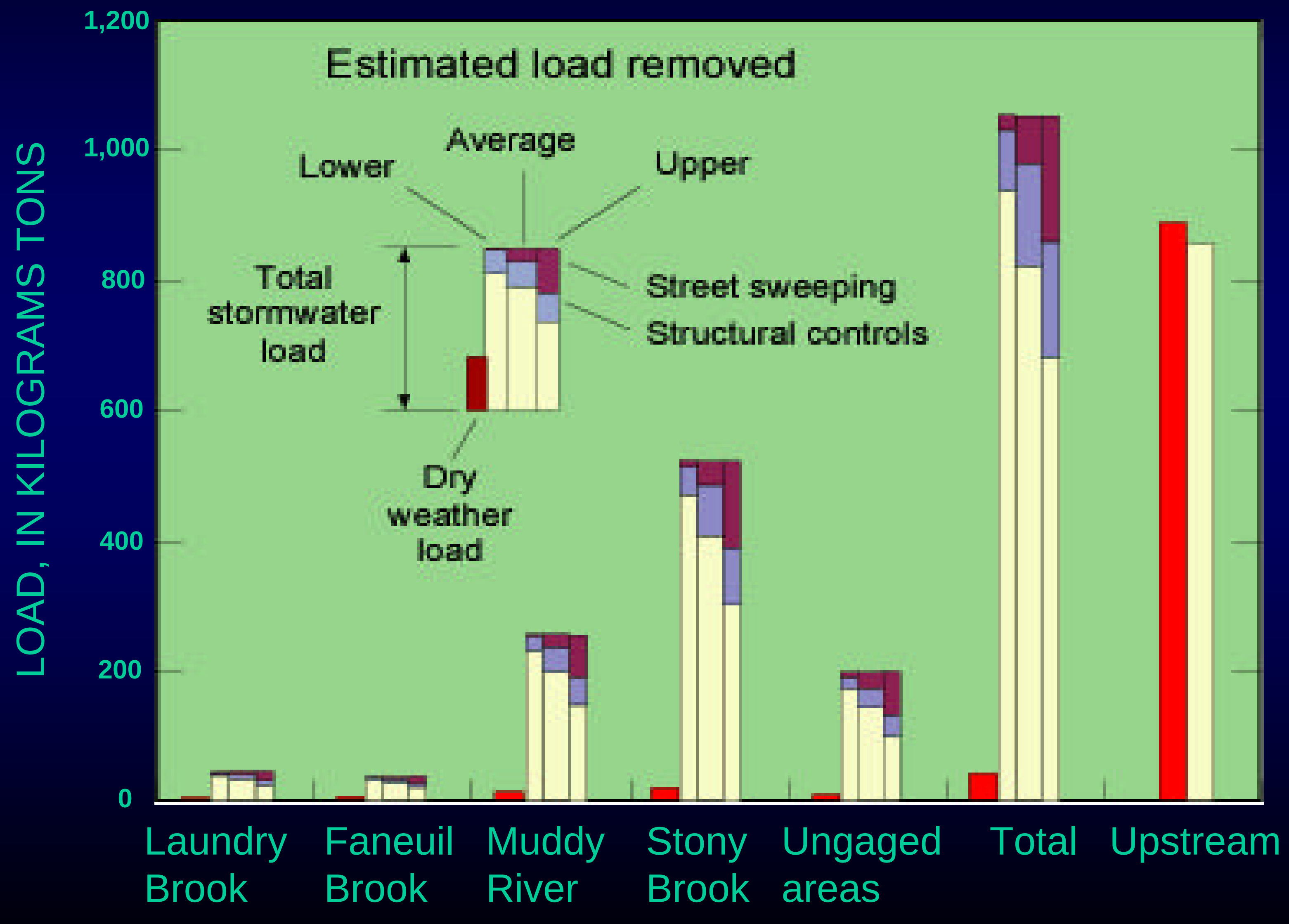
Fecal Coliform – 2000 WY



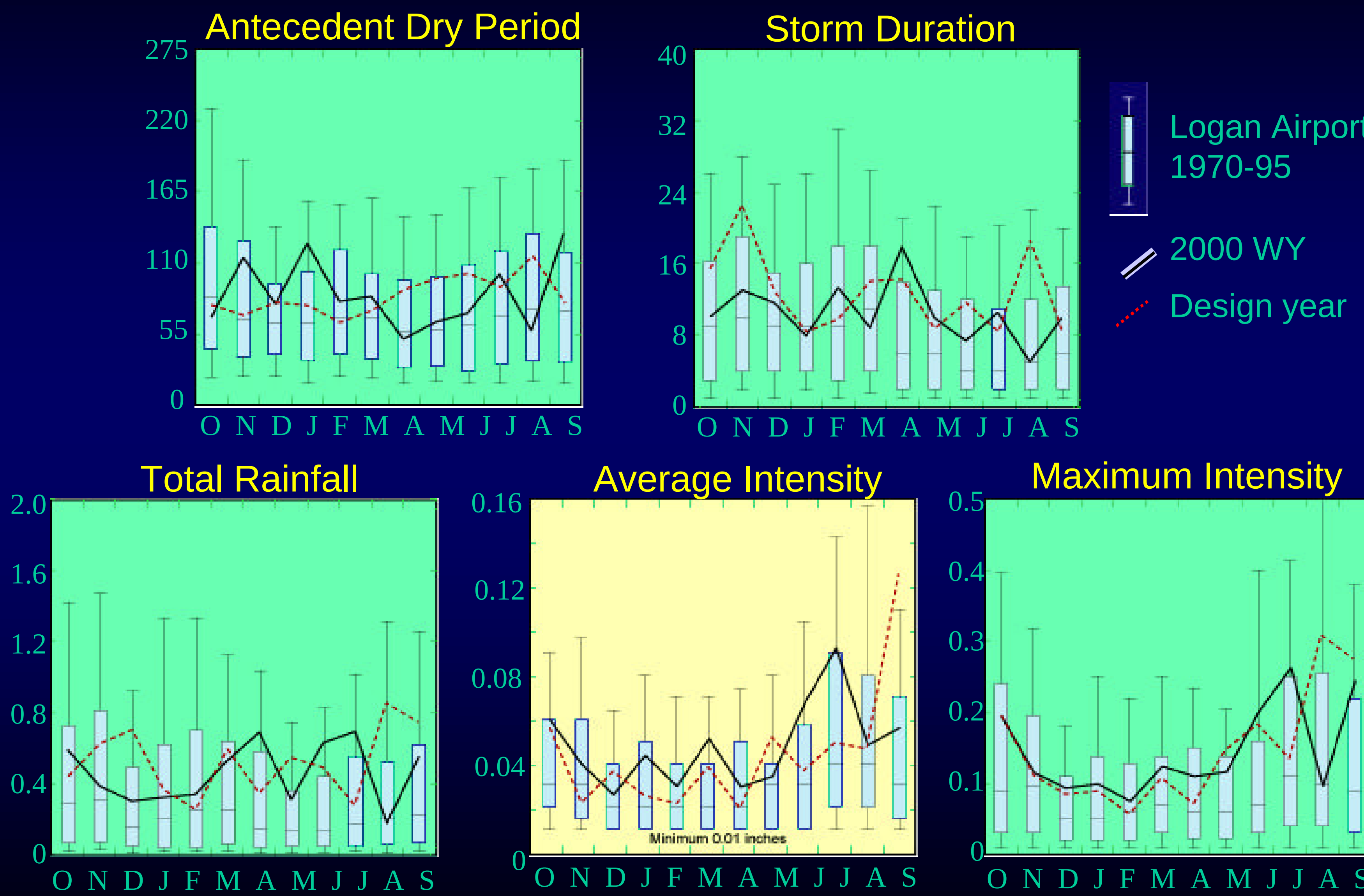
Total Phosphorus- 2000 WY



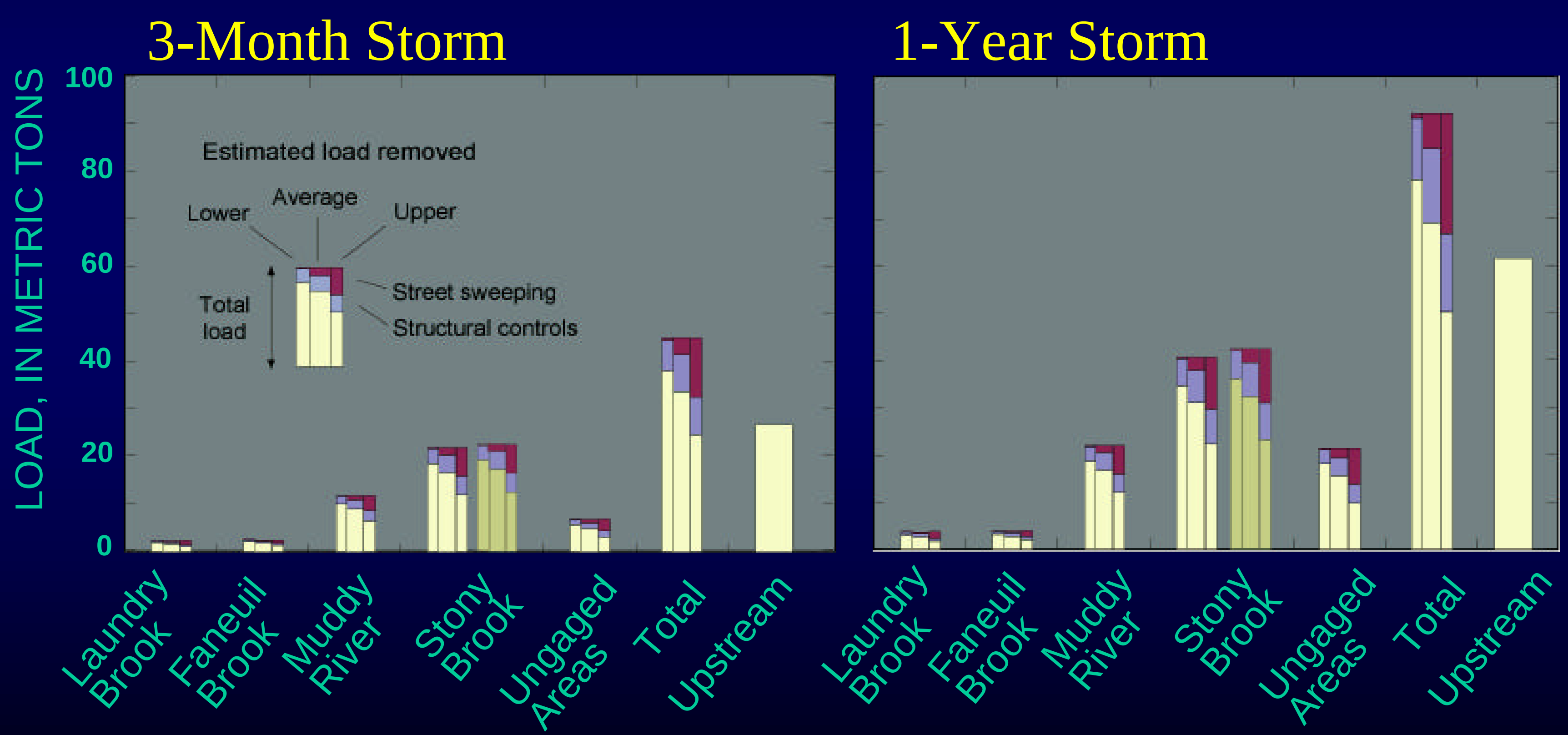
Total Lead- 2000 WY



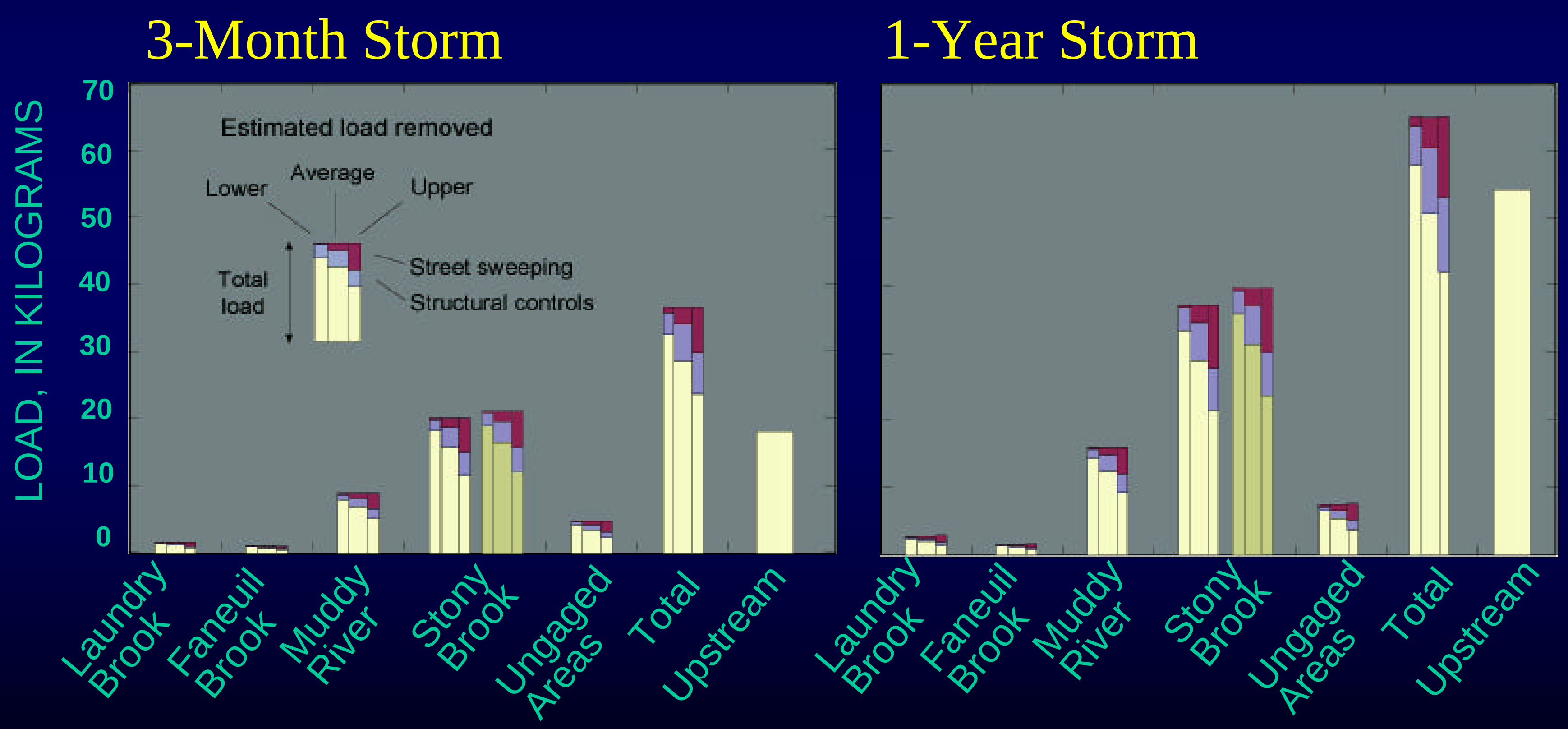
Storm Characteristics- Long-term, 2000WY & Design Year



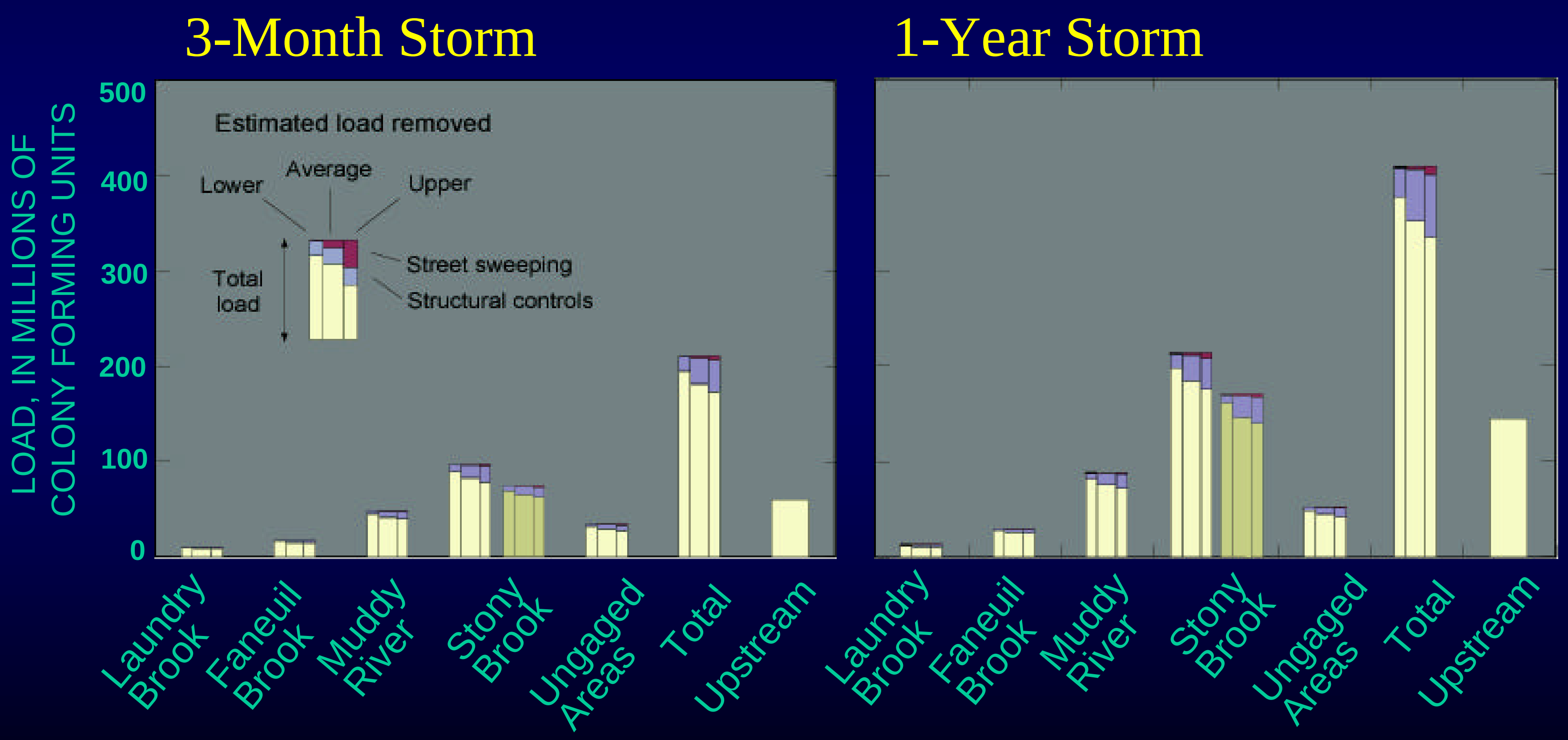
Suspended Sediment – Design Storm Loads



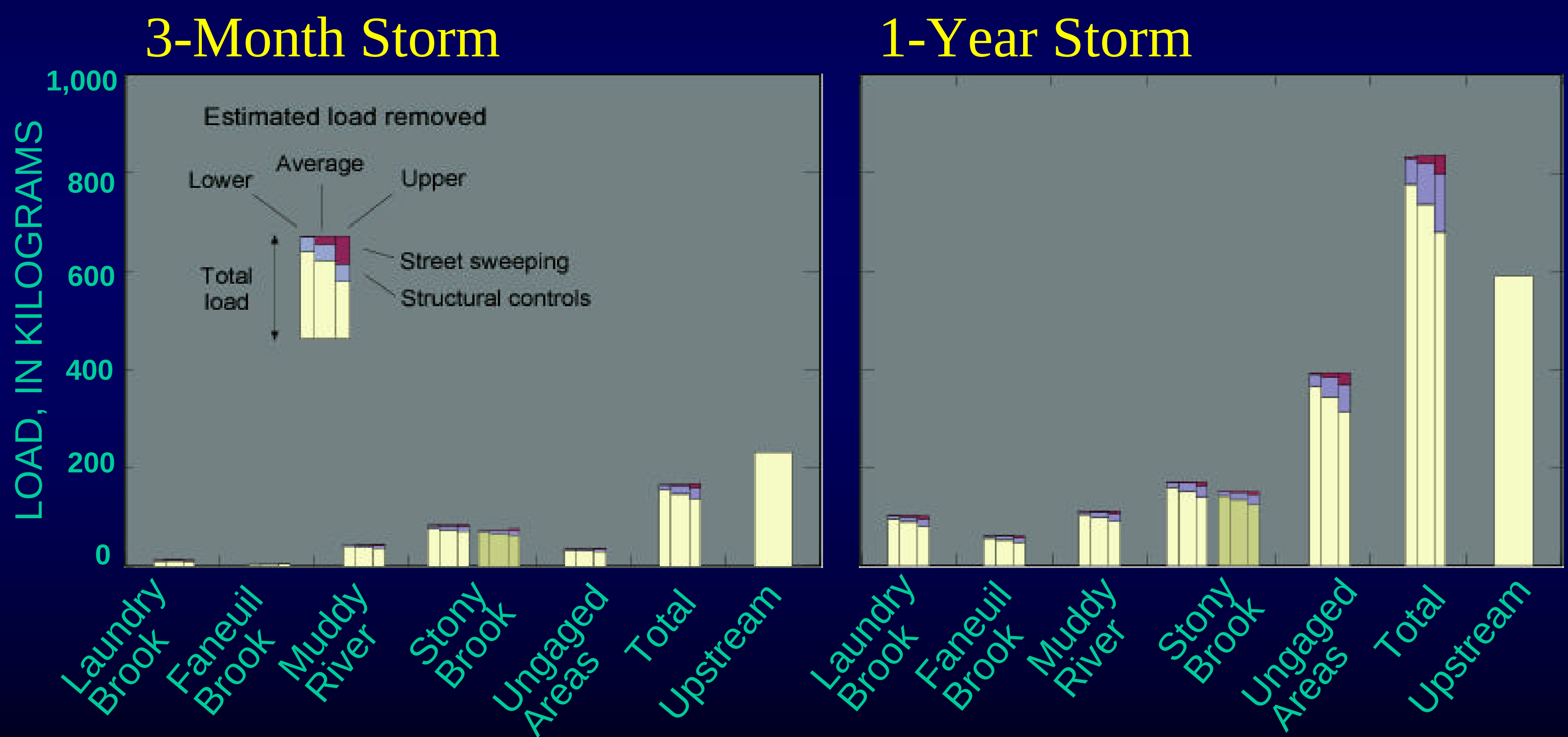
Total Lead – Design Storm Loads



Fecal Coliform – Design Storm Loads



Total Phosphorus – Design Storm Loads



Conclusions

- Structural control have a wide range of removal efficiencies,
- Removal efficiency is generally best for infiltration type controls and worst for biofiltration-bioretention type controls,
- Removal efficiency is generally best for sediment and lead and least for bacteria and phosphorus,
- Street sweeping technology has improved markedly over the past 20-30 years,
- Little independent data exist on performance of new sweepers and no data exist on effects of sweeping on bacteria.

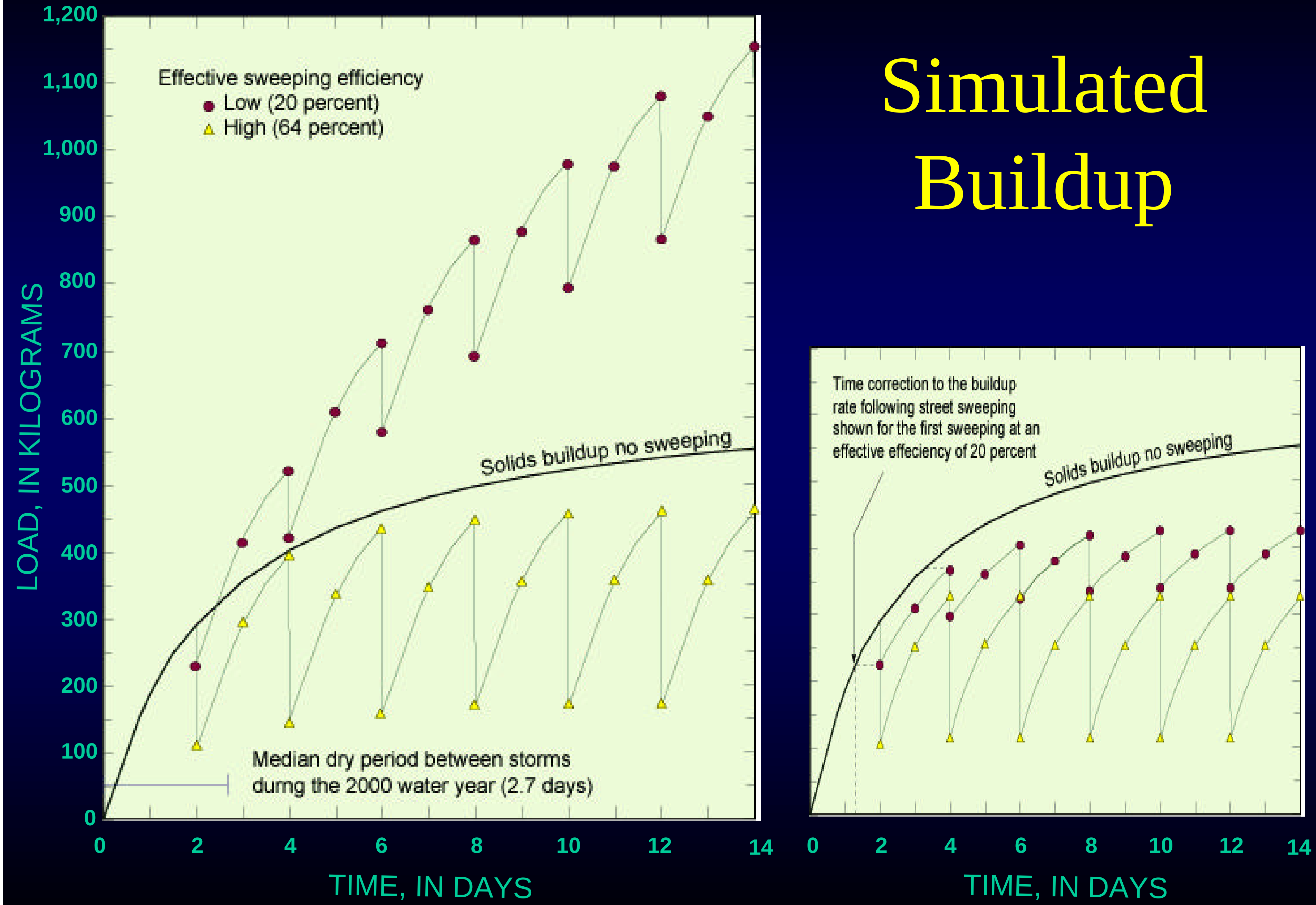
Conclusions (cont)

- Model variable values are non-unique and could effect the simulated removal by sweeping,
- Upper estimate, 35-45% decrease in lead and sediment and a 20% decrease in phosphorus and fecal bacteria (sweeping once weekly with the best available technology and upper quartile intensive of structural control retrofitting)
- Lower estimates, 4% decrease in sediment, lead and fecal and a 1.4% decrease in phosphorus (sweeping once monthly with low efficiency sweeper and lower quartile of structural control removal, includes loads above Watertown Dam)
- Load reductions are highly variable and only measurements of BMP effects can provide clear evidence of the benefits they may have on improving water quality.

Questions?

Photo courtesy of: Philip Greenspun   http://philip.greenspun.com

Simulated Buildup



Simulated Buildup Error